A novel approach using pulmonary artery catheter-directed rapid right ventricular pacing to facilitate precise deployment of endografts in the thoracic aorta

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Objective: **Controlled hypotension is critical for precise deployment of endografts in the thoracic aorta and for safe balloon dilation after deployment. We describe a novel approach to rapid right ventricular pacing using a pulmonary artery catheter (PAC) that is placed during the procedure for hemodynamic monitoring.**

Methods: **The study included 27 patients (20 men and seven women), with a mean age of 74 years, who underwent endograft placement in the thoracic aorta with PAC-directed rapid right ventricular pacing. Hemodynamic parameters, accuracy of deployment, complications related to rapid right ventricular pacing and PAC placement, presence of endoleaks, and postoperative complications were evaluated.**

Results: **PAC-directed rapid right ventricular pacing was performed during endograft deployment and balloon dilation after deployment without technical difficulty. Each patient underwent a median of two pacing episodes (range, 1-4). The length of each pacing episode was a mean of 11 seconds (range, 8-14 seconds). Mean pacing rate was 170 ± 15 beats/min, which achieved an average mean arterial pressure (MAP) of 42 ± 8 mm Hg. After pacing cessation, the recovery time of MAP to prepacing levels was <5 seconds (mean, 2 seconds) in all but one patient. All endografts were precisely deployed at a mean of 2 mm from the intended placement site, and there was no unintentional branch vessel coverage. One patient with severe valvular heart disease died. There were nine endoleaks, one postoperative stroke (4%), and one access wound hematoma (4%).**

Conclusions: **PAC-directed rapid right ventricular pacing is an effective method of inducing hypotension, enabling precise thoracic endograft deployment and safe balloon dilation after deployment. However, despite these advantages, the technique may be contraindicated in patients with severe valvular or ischemic heart disease. (J Vasc Surg 2012;55:1196-201.)**

Endovascular repair using thoracic aortic endografts is an accepted practice for the treatment of most patients with thoracic aortic aneurysms.[1,2] Despite increasing expertise and experience with endograft deployment in the thoracic aorta, the technical challenges of deploying these devices in a highly angulated aortic arch remain formidable. Adequate proximal and distal sealing zones in the thoracic aorta are prerequisites for endograft usage. The length of these sealing zones is often limited if the aneurysm is close to the aortic arch branches or visceral arteries. Accurate endograft deployment is necessary to avoid end-organ ischemia and endoleaks but is hindered by pulsatile aortic blood flow, which causes backward and forward movement of the endografts. Proximal hypertension that develops after partial endograft deployment can create a "windsock effect," pushing the endograft distally.

Rapid right ventricular (RV) pacing is an alternative effective method of lowering aortic flow and pressure, thereby minimizing the "windsock effect" during endograft deployment in the thoracic aorta. Most reports recommend placement of a cardiac pacing catheter under fluoroscopy via right or left femoral vein.[3-5] We present our experience with rapid RV pacing via pulmonary artery

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Table I. Demographic and clinical characteristics

Characteristic	*No. (%) or Mean ± SD*
Men	20 (74)
Women	7 (26)
Age, years	74 ± 11
Weight, kg	84 ± 15
Height, m	1.71 ± 0.08
Symptomatic aneurysm	3 (11)
ASA score, median	3
Smoking	16 (59)
Diabetes mellitus	6 (22)
Hypertension	23 (85)
Hyperlipidemia	14 (52)
Coronary artery disease	12 (44)
COPD	5 (18)
Concomitant aneurysms	9 (38)
Pre-op creatinine, mg/dL	0.97 ± 0.26

ASA, American Society of Anesthesiologists; *COPD,* chronic obstructive pulmonary disease; *SD,* standard deviation.

Table II. Anatomic characteristics and procedural data of aneurysm repair

Characteristic	*Result*
Aneurysm diameter, mean ± SD, mm	65 ± 8
Proximal neck diameter, mean ± SD, mm	32 ± 4
Distal neck diameter, median, mm	31 ± 4
Supra-aortic vessel incorporation[a]	9 (33)
Carotid-subclavian bypass or transposition	5 (15)
Carotid-carotid-subclavian bypass	3 (11)
Ascending aorta-innominate and L carotid bypass	1 (4)
Left subclavian artery fenestration	1 (4)
Elephant trunk reconstruction	1 (4)
Visceral artery incorporation	3 (11)
Celiac fenestration	1 (4)
Celiac and SMA fenestrations	1 (4)
Celiac, SMA and bilateral renal fenestrations	1 (4)

SD, Standard deviation; *SMA,* superior mesenteric artery.
[a]Mean interval from debranching procedure to endovascular repair was 13 days (2-41).

catheter (PAC), placed through the internal jugular vein accessed by the anesthesiologist during preparation for the thoracic endovascular aneurysm repair (TEVAR).

METHODS

After Institutional Review Board approval, we reviewed the clinical records and the radiographic studies of all consecutive patients for whom we used rapid RV pacing via a PAC during thoracic endograft placement since we first initiated this practice at the Mayo Clinic in March 2008. Twenty-seven patients underwent elective TEVAR for thoracic aortic aneurysms. Emergency procedures were excluded (total of two during the study period). The clinical, anatomic, and procedural data are presented in Tables I and II.

The preoperative proximal and distal landing zones, and the length of the landing zone covered by the endograft after deployment, were measured by computed tomography angiography (CTA) using centerline of flow analysis. Deployment precision was calculated as the difference between the available aortic landing zone length on preoperative CTA and the actual length covered by the endograft on the postprocedural CTA.

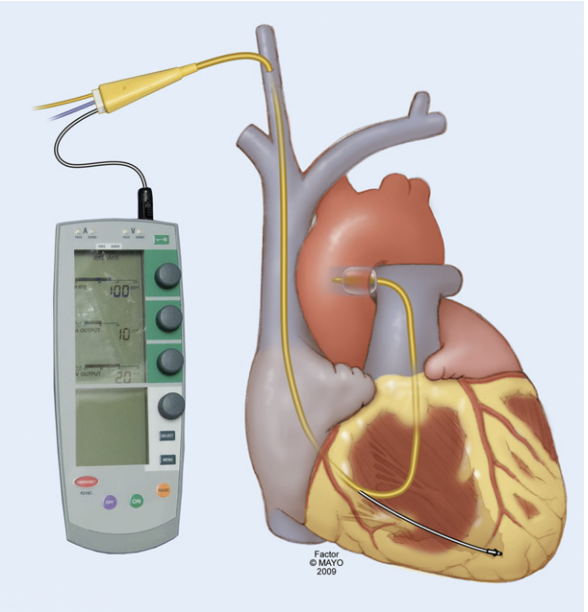

Fig 1. Pacing wire insertion via pulmonary artery catheter.

General anesthesia was used for all procedures. Patients were continuously monitored before, during, and after the endograft placement, including heart rate, invasive arterial pressure, and nasopharyngeal temperature. Chest radiograph, 12-lead electrocardiogram (ECG), and troponin levels were assessed in all patients immediately after the procedure. All patients were neurologically assessed in the recovery room and on each postoperative day during their hospital stay.

Description of rapid RV pacing procedure via PAC insertion. After induction of general anesthesia and endotracheal intubation, an introducer sheath (Arrow International Inc, Reading, Pa) is inserted into the right internal jugular vein under ultrasound guidance. A PAC with a pacing port is placed through the sheath (Fig 1). Once the RV pressure waveform is obtained in the RV-pacing port and a pulmonary artery pressure waveform is demonstrated in the distal port, the PAC is in position for adequate monitoring and ventricular pacing. A ventricular pacing wire is introduced via the RV-pacing port and connected to the bipolar pacer box. The pacer box is started at an amplitude of 10 mA and a rate 20 beats faster than the patient's baseline heart rate, and the wire is gently advanced until capture occurs. At this time, the pacer box is turned off and the wire is confirmed in adequate position for rapid RV pacing. A trial of rapid RV pacing is performed to evaluate the blood pressure drop and heart rate required to decrease the systolic blood pressure (SBP) to <60 mm Hg. This trial is performed with 10-second ventricular pacing

Fig 2. Trial of right ventricular pacing after the insertion of the pulmonary artery catheter and placement of the pacing wire via the pacing port. First strip: electrocardiogram (ECG); second strip: arterial blood pressure; third strip: pulmonary artery pressure.

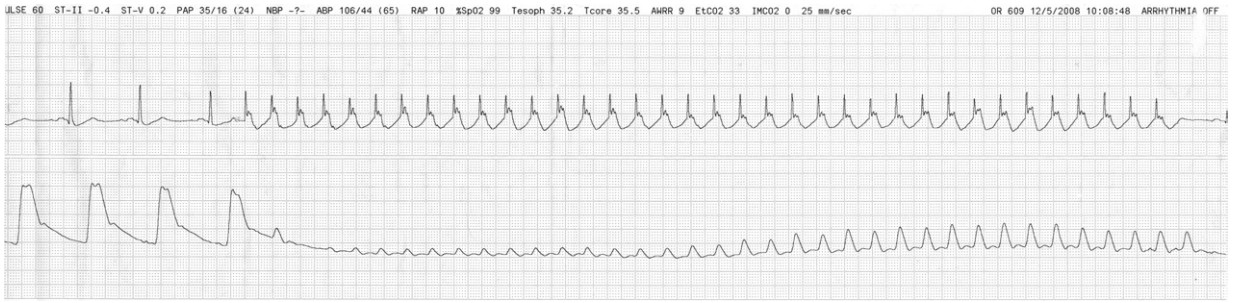

Fig 3. Rapid right ventricular pacing during endograft deployment in the thoracic aorta. First strip: electrocardiogram (ECG); second strip: arterial blood pressure.

periods, starting at a rate of 120 beats/min and increasing by 20 beats/min until successful controlled hypotension (<60 mm Hg) is achieved (Fig 2). Recovery of blood pressure and toleration of rapid RV pacing is also evaluated at this time. Availability of defibrillator pads is ensured prior to initial pacing testing.

Rapid RV pacing. Immediately before endograft deployment in the thoracic aorta, the anesthesiologist is alerted by the vascular surgeon to start rapid RV pacing. This is achieved at the rate tested when the PAC and wires were inserted. Graphic display of the effectiveness of pacing and controlled hypotension is printed and recorded (Fig 3).

Once the endograft is deployed, the surgeon alerts the anesthesiologist that is safe to stop pacing.

The ECG and blood pressure are printed and recorded to document effective, rapid, and controlled recovery of the patient's baseline heart rate and blood pressure (Fig 4). The procedure is repeated if needed for deployment of additional endografts or during balloon molding of the endograft.

RESULTS

Rapid RV pacing through a PAC was performed without technical difficulty in all 27 patients. The rapid RV pacing was used at the time of the endograft deployment and, if necessary, during balloon molding of the endograft. There were no complications related to PAC placement.

Pacing was achieved at an average heart rate of 170 beats/min and an average mean systolic pressure of 45 mm Hg. The mean duration of the pacing episodes was 11 seconds. During each pacing episode, an average of 3 seconds was required to reduce the mean SBP to goal, and the mean recovery time, defined as the time required for the mean arterial pressure to reach pre-pacing levels, was 2 seconds. With the exception of the intraoperative death, all patients experienced recovery ≤5 seconds of pacing cessation. A median of two episodes (range, 1-4) was performed per patient. The procedural characteristics, including the parameters relevant for the endograft deployment and rapid pacing, are summarized in Table III.

The proximal landing zone for the 27 patients in our series is depicted in the diagram in Fig 5. Rapid RV pacing was used in 23 of 27 patients to facilitate deployment of the endograft in the ascending, arch, or proximal descending thoracic aorta, and was used in four patients for accurate placement in the distal thoracic aorta near the mesenteric vessels. Deployment precision was calculated for each patient as the difference between the available aortic landing zone length, as measured on the preoperative CTA, and the

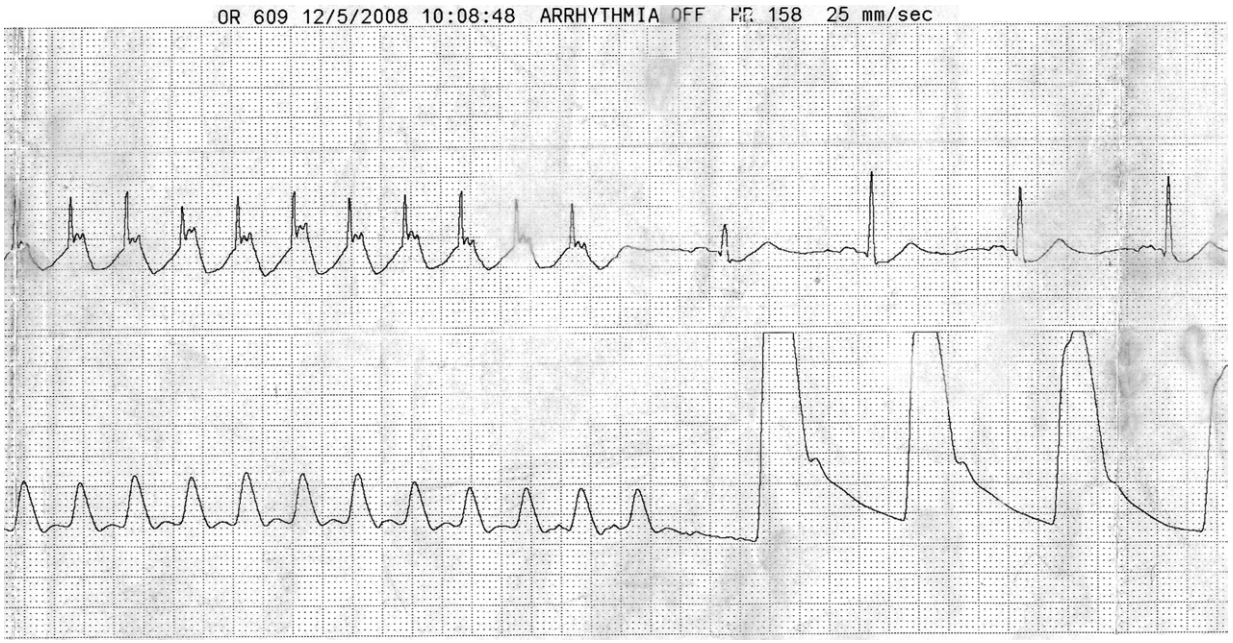

Fig 4. Recovery of the heart rhythm and blood pressure after cessation of the rapid right ventricular pacing and endograft deployment.

Table III. Procedural characteristics

Variable[a]	*Result*
Rapid pacing	
Rate, beats/minutes	170 ± 15
Episodes per patient	2 (1-4)
Episode duration, seconds	11 ± 4
MAP during pacing, mm Hg	45 ± 5
Time to achieve goal MAP, seconds	3 ± 1
Proximal/distal neck length	
Available, mm	22 ± 5
Covered, mm	20 ± 3
Precision of deployment, mm	2 ± 2
Spinal drain	13 (48)
Intravascular ultrasound	4 (18)
Operative time, minutes	167 ± 48
Estimated blood loss, mL	100 ± 105
Intraoperative transfusion, mL	150 ± 250

MAP, Mean arterial pressure.
[a]Data are mean ± SD, standard deviation, median (range), or No. (%).

actual landing zone length covered by the endograft, as measured on the postprocedure CTA. The precision of endograft in these 27 patients averaged 2 mm.

After the procedure, the PAC was removed. All patients were continuously monitored for the first 24 hours and received a postoperative ECG, and troponin level measurements immediately after the procedure and on the morning of postoperative day 1. There was one intraoperative death in a patient with severe mitral regurgitation and moderate aortic regurgitation that did not recover after multiple episodes of pacing. Four patients (15%) developed atrial fibrillation with rapid ventricular response after the procedure, requiring intensive care unit admission and electric or pharmacologic cardioversion. One patient had troponin elevation (0.01 to 0.1 ng/mL), but was ruled out for myocardial infarction, and another developed an embolic stroke (4%). No postoperative renal insufficiency was noted. The median length of stay after the TEVAR procedure was 2 days (range, 1-5). Twenty-six of the 27 patients were alive at 30 days. There were nine endoleaks (five type Ia, one type Ib, and three type II endoleaks), of which two required reintervention. No unintentional branch vessel coverage occurred. The immediate outcome of the patients in our series is summarized in Table IV.

DISCUSSION

The challenge of endograft displacement caused by pulsatile blood flow during TEVAR has long been recognized. Controlled hypotension allows exact positioning of the device during deployment, especially with a short proximal or distal landing zone. The ideal method to induce controlled hypotension should be reliable, easy to perform, applicable to most patients, and should not significantly add to the duration and complexity of the procedure. In addition, the level of hypotension should be predictable, adjustable, and achieved repetitively, if needed. The onset and offset of action should be immediate with minimal side effects.

Previous reports have described rapid RV pacing using a pacing catheter placed via the femoral vein as a safe and reliable method of reducing pulsatile blood pressure, with nearly immediate onset and offset of action.[3-5] In addition, the pacing rate is readily titrated. In our series, the rapid RV pacing was done using a PAC inserted by the anesthesiol-

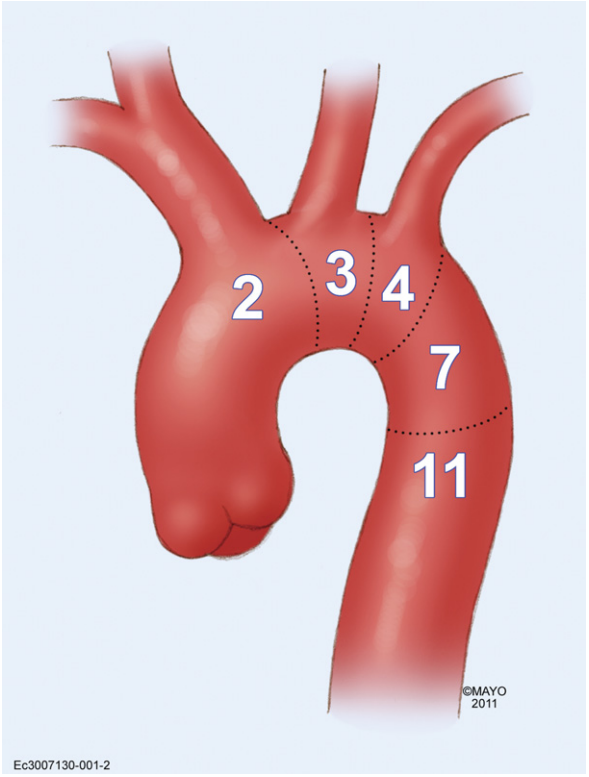

Fig 5. Distribution of the proximal landing zone for the deployed endografts in 24 patients.

Table IV. Thirty-day outcomes

Outcome parameter	*No. (%) Mean ± SD median (IQ range)*
Total endoleaks	9 (35)
Type Ia	5 (19)
Type Ib	1 (4)
Type II	3 (12)
Complications	
PAC-related	0
Atrial fibrillation[a]	4 (15)
Troponin elevation[b]	1 (4)
Neurologic (stroke, paraplegia)	1 (4)
Access-/wound-related	1 (4)
Hospital length of stay	2 (1-5)
Mortality	1 (4)

IQ, Interquartile range; *PAC,* pulmonary artery catheter; *SD,* standard deviation.
[a]Atrial fibrillation that required ICU admission and cardioversion (medical or electrical).
[b]Transient troponin elevation, myocardial infarction was ruled out.

ogist via the internal jugular vein rather than the femoral vein. Since a central venous catheter often is placed in the internal jugular vein in patients undergoing TEVAR for hemodynamic monitoring and administration of vasoactive medications, the addition of a PAC does not significantly increase the complexity and duration of the anesthesia preparation time. Moreover, it avoids the need for additional femoral vein access, which has been reported to have a higher complication rate than internal jugular vein access.[6]

Serious complications with temporary cardiac pacing of short duration are rare.[7] In the absence of a history of ventricular tachycardia or severe heart failure, the risk of a ventricular tachyarrhythmia occurring is <1%. Complications related to central venous catheterization, including arterial puncture, subcutaneous hematoma, hemothorax, venous air embolism, and asystole, are rare in experienced hands.[8] Complications related to PAC insertion are also rare but potentially serious and include ventricular arrhythmias,[6] transient heart block,[9] and pulmonary artery perforation.[10]

In our series, there were no PAC placement complications. However, one intraoperative death occurred in a patient with severe valvular disease and moderate left ventricular dysfunction. The patient did not recover after the third pacing episode, his rhythm degenerated to ventricular fibrillation, and he expired despite defibrillation attempts and advanced cardiac life support. Therefore, rapid RV pacing may be contraindicated in patients with impaired myocardial reserve, or poor tolerance to tachycardia, such as those with severe coronary artery or valvular heart disease, or hypertrophic cardiomyopathy.

In the few published reports on this subject,[3-5] a right RV pacing catheter is placed under fluoroscopy via the right or left femoral vein, followed by placement of temporary pacing wires performed in collaboration with a cardiologist. The method we present uses a PAC positioned in the standard fashion at the beginning of the procedure, which does not delay endograft placement to allow for right heart catheterization. Moreover, the anesthesiology team in the vascular suite is familiar with this equipment. All the survivors experienced rapid onset of pacing and offset of action and accurate endograft deployment.

CONCLUSIONS

PAC-directed right RV pacing is an effective method of inducing hypotension, enables precise thoracic endograft deployment, and safe balloon dilation after deployment. It avoids femoral venous access and its potential complications, and simplifies the procedure by using resources readily available to the vascular surgeon. This technique can be done with short pacing intervals, and allows rapid recovery to baseline heart rate and mean arterial pressure.

Despite these advantages, patient selection and appropriate expertise is crucial to avoid intraoperative complications. Patients with poor tolerance to tachycardia, decreased myocardial reserve, or severe coronary artery or valvular disease, congestive heart failure, hypertrophic cardiomyopathy, and severe valvular heart disease may be at high risk for complications.

AUTHOR CONTRIBUTIONS

Conception and design: JR,
Analysis and interpretation: JR, JP, GO, TB, CH
Data collection: JR, CH, JP, GO, TB
Writing the article: JR, JP, GO, TB, CH

Critical revision of the article: JR, CH, JP, TB, GO, MK, PG
Final approval of the article: JR
Statistical analysis: JR, CH, JP
Obtained funding: JR,
Overall responsibility: JR

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